EVALUATION OF DSH/JP-8 FUEL BLENDS: REGARDING ITS EFFECTIVENESS FOR USE IN GROUND VEHICLES AND EQUIPMENT

INTERIM REPORT
TFLRF No. 482

By
Douglas M. Yost
Edwin A. Frame

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

For
Patsy A. Muzzell
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-15-C-0030 (WD002)

October 2016

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U.S. Army TARDEC Fuels and Lubricants
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EXECUTIVE SUMMARY

Endurance tests were performed using a motorized pump stand to define the effects of fuel and fuel additives on full-scale fuel injection system equipment durability. A test was performed utilizing a fuel injection pump operating procedure that targeted 500-Hours of operation. The specific test performed included:

- Volumetric blend of 20-percent DSH8 and 80-percent JP-8, the minimum level of DCI-4A CI/LI additive specified as 9-ppm, with a fuel inlet temperature of 77 °C.

The following conclusions can be made from the cumulative knowledge of utilizing JP-8, synthetic aviation kerosene fuel blends, and 20/80 DSH8/JP-8 in diesel rotary fuel injection pumps at elevated temperature:

- For elevated fuel inlet temperature operation, even with petroleum JP-8 at 77 °C, the maximum effective CI/LI concentration is required to provide adequate wear protection.
- For elevated fuel inlet temperature operation, with 20/80 DSH8/JP-8 at 77 °C, the minimum effective CI/LI concentration proved to be borderline effective for the 500-Hours of testing.
- A 20/80 blend of DSH8/JP-8 with 9-ppm CI/LI operated at 77 °C fuel inlet temperature will allow 500-Hours of rotary pump operation. However the performance degradation of the fuel injection pumps at 500-Hours could impact engine governor operation, and component inspections suggested excessive transfer pump liner wear.

The technical feasibility of using DSH8/JP-8 fuel at elevated temperatures in rotary fuel injection equipment when blended with a CI/LI additive has been investigated:

- At the minimum effective concentration of a QPL-25017 CI/LI additive, DSH8/JP-8 blends can be utilized in regions where rotary fuel injection pump equipped engines are exposed to elevated fuel inlet temperatures for short durations.
- It is recommended that blends of DSH8/JP-8 fuels include the addition of the maximum effective concentration of CI/LI for use in diesel rotary fuel injection equipment at elevated ambient temperatures to reduce transfer pump wear.

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FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period September 2015 through October 2016 under Contract No. W56HZV-15-C-0300. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT) served as the TARDEC contracting officer's technical representative and the project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical and administrative support staff.

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ACRONYMS AND ABBREVIATIONS

° C	degrees Centigrade
ASTM	ASTM International
BOCLE	Ball-on-Cylinder Lubricity Evaluator
cc	Cubic Centimeter
CI/LI	Corrosion Inhibitor/Lubricity Improver
cm	Centimeter
cSt	Centistokes
DSH8	Direct Sugar to Hydrocarbon Fuel
ft	Foot
FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene
HEFA	Hydro-treated Esters and Fatty Acid(s)
HFRR	High Frequency Reciprocating Rig
HMMWV	High Mobility Multi-Purpose Wheeled Vehicle
hr	Hour
in	Inch
JP-8	Jet Propulsion 8
kW	Kilowatt
L	Liter
lb	Pound
m	Meter
MEOH	Methanol
mg	milligram
mg/L	milligrams per Liter concentration
mL	milliliter
mm	millimeter
ppm	parts per million
psi	pounds per square inch
QPL	Qualified Products List
RPM	rotation(s) per minute
SwRI®	Southwest Research Institute®
SOW	Scope of Work
SPK	Synthetic Paraffinic Kerosene
TACOM	Tank Automotive and Armaments Command
TARDEC	Tank Automotive RD&E Center
TFLRF	TARDEC Fuel and Lubricants Research Facility
WOT	Wide Open Throttle
WD	Work Directive
WSD	Wear Scar Diameter

1.0 BACKGROUND & INTRODUCTION

The United States Department of Defense Operational Energy Strategy has outlined a goal “to diversify its energy sources and protect access to energy supplies to have a more assured supply of energy for military missions”[1]. In accordance with this directive, the U.S. Army had conducted extensive research to investigate alternative fuels viability in military equipment. This has included basic chemical and physical property investigation to identify surrogate fuel sources with similar properties as traditional petroleum fuels, to full scale equipment and fleet testing to determine resulting component and vehicle performance. This report covers investigation into the use of blended Direct Sugar to Hydrocarbon (DSH8) based fuel and traditional petroleum derived JP-8 in a fuel sensitive rotary fuel injection pump at elevated fuel inlet temperatures. All work was completed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, TX.

Initial tests with synthetic aviation kerosene fuels revealed severe wear and extreme life reduction of rotary fuel injection pumps for diesel engines. The untreated fuels caused performance degrading wear on rotary fuel injection pumps within 25-hours of operation on the untreated fuel.[2,3] However, prior work with synthetic fuels have shown those fuels responded well to the addition of a Corrosion Inhibitor/Lubricity Improver (CI/LI) additive to extend the life of the rotary fuel injection equipment. In addition, it is likely that most synthetic fuel will be used as a blending component with petroleum JP-8 fuel at a maximum 50-percent in order to maintain fuel density above the JP-8 specification minimum.

In conducting previous additive treated synthetic fuel pump stand tests, it was found that the tests could be operated to conclusion at 500-hours if the maximum concentration of CI/LI additive is utilized at 40 °C fuel inlet temperature. Prior testing also indicated a synthetic fuel that is blended 50-percent with JP-8, and treated with an approved CI/LI additive, will also provide adequate diesel fuel injection pump wear protection at 40 °C fuel inlet temperature.[4,5,6]

2.0 TEST OBJECTIVE

The objective of this test was to evaluate the durability of the fuel injection system utilized on a V8-cylinder General Engines Products (GEP) 6.5L turbocharged engine with a 20%DSH8/80%JP-8 fuel blend at an elevated fuel inlet temperature of 77 °C for 500-hours. The CI/LI additive DCI-4A was utilized at 9-ppm to treat the test fuel.

3.0 TEST APPROACH

Endurance tests were performed using a motorized pump stand to define the effects of fuel and fuel additives on full-scale fuel injection equipment durability. The test series attempted to determine the level of fuel injection system degradation due to wear and failure of the boundary film using the HMMWV engine opposed-piston, rotary distributor, fuel injection pumps with a Direct Sugar to Hydrocarbon (DSH8) synthetic fuel blended with petroleum JP-8 with CI/LI additive treatment. A test was performed utilizing a fuel injection pump operating procedure that targeted 500-Hours of operation. The specific test performed included:

- Volumetric Blend of 20-percent DSH8 and 80-percent JP-8, the minimum level of DCI-4A CI/LI additive specified as 9-ppm, with a fuel inlet temperature of 77 °C.

3.1 FUEL PROPERTIES

As specified in the Scope of Work (SOW) for this project, the desire was to evaluate a 20/80 blend of DSH8/JP-8 to determine changes in injection pump durability with a 9-ppm CI/LI additive concentration at elevated fuel inlet temperature. The use of only 20% DSH8 in the fuel blend was due to DSH8 impacts on low temperature viscosity limits [2]. Table 1 and Table 2 show the resulting chemical and physical analysis of the test fuels and blend evaluated and requirements cited by MIL-DTL-83133, Detail Specification: Turbine Fuel, Aviation, Kerosene Type, JP-8, NATO F35, and JP-8 +100. Table 2 also includes the speed of sound and bulk modulus data for the 20/80 DSH8/JP-8 test fuel and JP-8.

Table 1. Neat DSH8 Fuel Chemical/Physical Properties

Test	ASTM Method	Units	DSH8 CL15-8589 Results
Acid Number	**D3242**	mg KOH / g	0.007
Bromine Index of Petroleum Hydrocarbons	**D2710**	g	2.17
Chemical Composition	**D1319**		
Aromatics		vol %	0.5
Olefins		vol %	0.6
Saturates		vol %	98.9
Carbon Hydrogen Content	**D5291 CH**		
Carbon		mass %	85.00
Hydrogen		mass %	15.16
Nitrogen Content	**D4629**	ppm	<1.0
Karl Fisher Water Content	**D6304**	ppm	50
Sulfur Content	**D4294**		
Sulfur		mass %	<0.005
Sulfur in ppm		ppm	<100
Distillation	**D86**		
IBP		°C	244.0
5% Rcvd		°C	244.8
10% Rcvd		°C	244.9
15% Rcvd		°C	244.9
20% Rcvd		°C	245.0
30% Rcvd		°C	245.0
40% Rcvd		°C	245.0
50% Rcvd		°C	245.0
60% Rcvd		°C	243.3
70% Rcvd		°C	245.0
80% Rcvd		°C	245.1
90% Rcvd		°C	245.1
95% Rcvd		°C	245.1
FBP		°C	245.4
Residue		%	1.5
Loss		%	1
T90-T10		°C	0.2
Flash Point	**D93**	°C	106.5
Net Heat of Combustion	**D4809**	MJ/kg	43.9
Density (15 °C)	**D4052**	kg/m³	771.9
Freeze Point (Manual)	**D2386**	°C	>-80.0
Kinematic Viscosity	**D445**		
Test Temperature		°C	-20
Viscosity		mm²/s	13.66
Kinematic Viscosity	**D445**		
Test Temperature		°C	40
Viscosity		mm²/s	2.31
Kinematic Viscosity	**D445**		
Test Temperature		°C	80
Viscosity		mm²/s	1.25
Derived Cetane Number	**D6890**		
Ignition Delay		sec	3.439
Derived Cetane		--	58.73
Lubricity (BOCLE)	**D5001**	mm	0.528
JFTOT	**D3241**		
Test Temperature		°C	325
ASTM Code		rating	1
Maximum Pressure Drop		mmHg	0.1
Ellipsometer		nm	13.828
Total Volume		cm^3	3.28e-6
Gum Content	**D381**	mg / 100 mL	1

Table 2. Fuel Analysis for 20% DSH8 80% JP-8 Blend and JP-8 Blend Stock

Test	ASTM Method	Units	20% DSH8 80% JP-8 CL15-8590 Results	JP-8 CL15-8591 Results
Saybolt Color	**D156**	--	22	20
Acid Number	**D3242**	mg KOH / g	0.004	0.006
Chemical Composition	**D1319**			
Aromatics		vol %	14.7	17.2
Olefins		vol %	0.9	0.9
Saturates		vol %	84.4	81.9
Sulfur Content	**D4294**			
Sulfur		mass %	0.08	0.099
Sulfur in ppm		ppm	796	986
Sulfur Mercaptan	**D3227**	mass %	0.0004	0.0004
Doctor Test	**D4952**	--	Sweet	Sweet
Distillation	**D86**			
IBP		°C	178.6	175.0
5% Rcvd		°C	190.3	185.7
10% Rcvd		°C	192.2	188.2
15% Rcvd		°C	196.5	190.1
20% Rcvd		°C	199.4	193.0
30% Rcvd		°C	206.1	198.0
40% Rcvd		°C	211.5	202.5
50% Rcvd		°C	216.9	206.9
60% Rcvd		°C	223.1	211.8
70% Rcvd		°C	229.6	217.5
80% Rcvd		°C	236.3	224.6
90% Rcvd		°C	243.3	234.6
95% Rcvd		°C	249.7	243.1
FBP		°C	251.9	252.4
Residue		%	1.3	1.1
Loss		%	2.2	0.6
T90-T10		°C	51.1	46.4
Flash Point	**D93**	°C	61.5	57.5
Density (15 °C)	**D4052**	kg/m³	790.6	795.4
Freeze Point (Manual)	**D2386**	°C	-56	-53
Net Heat of Combustion	**D4809**	MJ/kg	43.1	42.8
Hydrogen Content (NMR)	**D3701**	mass %	15.42	15.45
Smoke Point	**D1322**	mm	28.5	25.3
Naphthalene Content	**D1840**	vol %	0.78	0.79
Calculated Cetane Index	**D976**	--	54.9	49.2
Copper Strip Corrosion	**D130**			
Test Temperature		°C	100	100
Test Duration		hrs	2	2
Rating		--	2A	2A
JFTOT	**D3241**			
Test Temperature		°C	260	260
ASTM Code		rating	1	1
Maximum Pressure Drop		mmHg	0.1	0.1
Ellipsometer		nm	6.668	4.919
Total Volume		cm^3	1.22E-06	5.622E-07
JFTOT	**D3241**			
Test Temperature		°C	325	325
ASTM Code		rating	4P	>4P
Maximum Pressure Drop		mmHg	0.0	0.1
Ellipsometer		nm	164.641	216.439

Table 2. Fuel Analysis for 20% DSH8 80% JP-8 Blend and JP-8 Blend Stock

Test	ASTM Method	Units	20% DSH8 80% JP-8 CL15-8590 Results	JP-8 CL15-8591 Results
Total Volume		cm^3	-	-
Gum Content	D381	mg / 100 mL	<1	1
Particulate Contamination in Aviation Fuels	D5452			
Total Contamination		mg/L	0.5	0.4
Total Volume Used		mL	1000	1000
Water Reaction	D1094			
Volume Change of Aqueous Layer		mL	1	1
Interface Condition		rating	1B	1B
Separation		--	2	2
Water Separation	D7224	rating	72	70
Fuel System Icing Inhibitor (FSII) Content	D5006			
Test Temperature		°C	20.5	20.5
FSII Content		vol %	0.10	0.11
Electrical Conductivity	D2624			
Electrical Conductivity		pS/m	301	451
Temperature		°C	21	21
Kinematic Viscosity	D445			
Test Temperature		°C	-20	-20
Viscosity		mm²/s	5.37	4.471
Kinematic Viscosity	D445			
Test Temperature		°C	40	40
Viscosity		mm²/s	1.45	1.34
Kinematic Viscosity	D445			
Test Temperature		°C	80	80
Viscosity		mm²/s	0.88	0.82
Derived Cetane Number	D6890			
Ignition Delay		sec	4.133	4.307
Derived Cetane		--	49.6	47.78
Lubricity (BOCLE)	D5001	mm	0.529	0.542
Lubricity (HFRR)	D6079			
Test Temperature		°C	60	60
CI/LI Concentration		mg/L	9	9
Wear Scar Diameter		um	670	684
Speed of Sound	SpdofSnd			
Temperature		°C	30.1	30
Speed of Sound		m/s	1267.0	1267.3
Bulk Modulus		psi	181,421	182,580

3.2 STANADYNE ROTARY FUEL INJECTION SYSTEM

Rotary distributor fuel injection pumps are fuel lubricated, thus sensitive to fuel lubricity. Highly refined, low sulfur and low aromatic fuels can cause substantial performance degradation with these pumps. Wear seen in the Stanadyne pumps could be interpolated to rotary distributor pumps of other manufacturers.

3.3 PUMP TEST PROCEDURE

Full-scale equipment tests were performed using new fuel injection pumps and fuel injectors with the test fuel. The pump tests were performed in duplicate in order to obtain average wear results. Two fifty-five gallon drums of the appropriate test fuel are normally required for each 500-hour pump tests. The 500-hour tests were performed under steady state conditions at maximum fuel delivery for the test pump, as summarized in Table 3. The tests were occasionally halted and restarted as necessary due to scheduling requirements or technical reasons. The pumps were started gradually to prevent seizure due to thermal shock. To further reduce the risk of seizure due to differential expansion, the fuel was not preheated prior to starting the pumps.

Table 3. Pump Operating Conditions

Parameter:	Value:
Duration, hours	500
Speed, RPM	1700
Fuel Inlet Temperature, □C	77
Throttle position	Full
Fuel-drum temperature, □C	<30

The test stand included injection flow and pump return pipes, lift pumps, filters, flow meters, a fuel pre-heater and a heat exchanger to reduce the temperature of the fuel before returning to the storage tank. A schematic diagram of the fuel supply system proposed for the pump stand is shown in Figure 1. The temperature of the incoming fuel to each fuel injection pump was controlled to 77 °C. The high-pressure outlets from the pumps were connected to fuel injectors assembled in a collection canister.

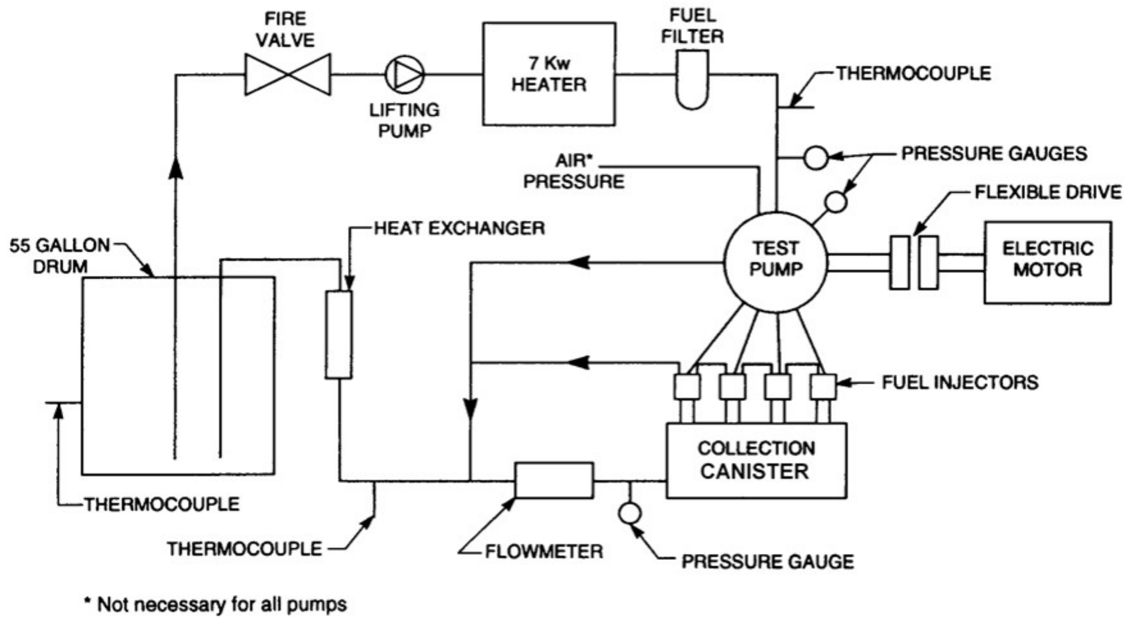


Figure 1. Representative Schematic Diagram of Fuel Delivery System

3.4 LABORATORY SCALE WEAR TESTS

Stanadyne has indicated the lubricity of the test fuel should be determined prior to testing. Stanadyne has recommended the test fuel be changed at 250-hour intervals. The laboratory scale wear performed on the test fuels was the Ball on Cylinder Lubricity Evaluator (BOCLE) procedure described in ASTM D-5001, because that procedure is called out for aviation kerosene fuels and additives. The ASTM D-6079 High Frequency Reciprocating Rig (HFRR) wear tests was also performed on the test fuel. The bench test results are shown in Table 4.

Table 4. Beach Wear Test Results for 20/80 DSH8/JP-8 at 9-ppm CI/LI Concentration

CI/LI Concentration	ASTM Method	Description	Result	Units
9-ppm	D 5001	BOCLE	0.529	mm
	D 6079	HFRR	670	µm

3.5 EVALUATION OF THE PUMPS USING A CALIBRATED TEST STAND

Prior to and following each scheduled pump test, the performance of each of the Stanadyne pumps was evaluated using a calibrated test stand. The objective of the calibration stand evaluation is to define the effect of the durability testing on pump performance. The calibration stand evaluations were performed at an authorized pump distributor. No adjustments were made to any of the pumps to achieve the manufacturer's specifications, either before, during, or following the scheduled pump stand tests.

The appropriate inspection and test procedures for determining fuel injector performance were followed prior to, and after each fuel evaluation.

3.6 PUMP DISASSEMBLY AND WEAR EVALUATION

The fuel injection pumps and fuel injectors were disassembled at SwRI® following completion of the durability tests and the subsequent evaluation using the calibrated test stand. A SwRI disassembly and rating procedure was originally developed for the U.S. Army for use with Stanadyne fuel injection equipment. Each sliding contact within the pump is rated on a scale from 0 to 5, with 0 corresponding to no wear and 5 corresponding to severe wear and failure. The wear scars on components throughout the pump are evaluated visually and quantitative measurements of wear volume were made on the critical pump components. The SwRI procedure looks at all wear contacts within the fuel injection pump, which are lubricated by the fuel.

4.0 PUMP TEST STAND EVALUATIONS

4.1 ROTARY PUMP TEST PROCEDURE

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-6282, for a General Engine Products 6.5L turbocharged engine application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure 2.

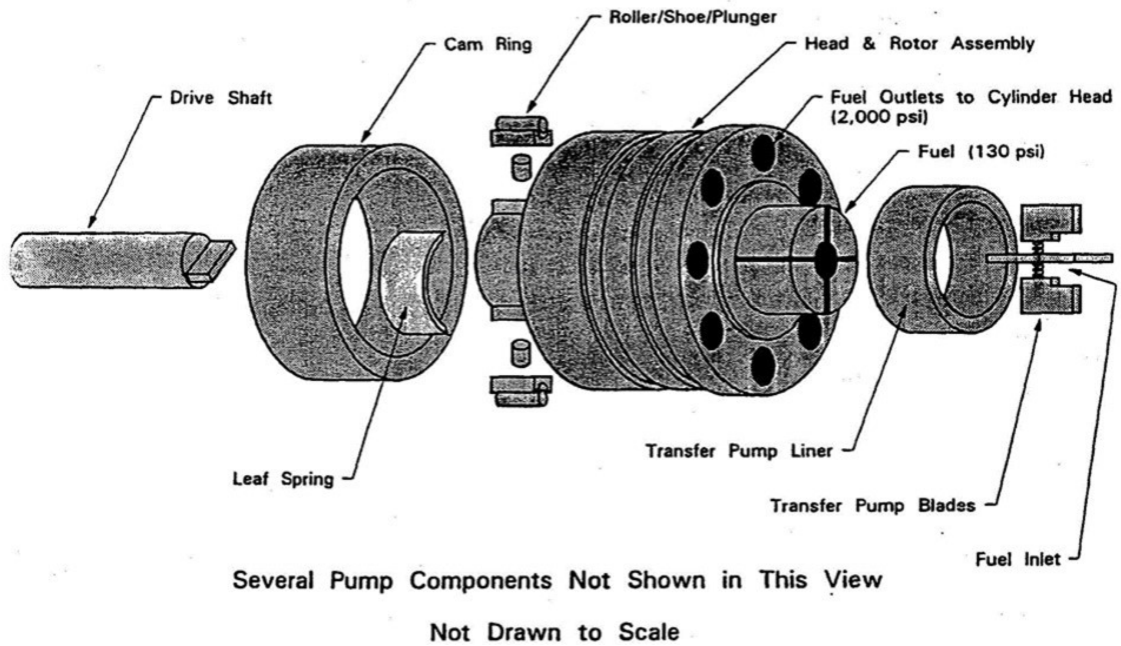


Figure 2. Schematic Diagram of Principal Pump Components

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade heights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-6282 model. The specification calls for a roller-to-roller dimension setting of 50.19 mm ± .026 mm, with a 0.2 mm maximum eccentricity. All pumps were set prior to testing with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured. Although there are not any min-max specifications other than initial assembly values, wear calculation from the roller-to-roller dimension is an excellent benchmark for the effects of fuel lubricity.

The pumps were reassembled and pre-test performance evaluations were conducted. The pumps were then mounted on the test stand and operated at 1700-RPM; with the fuel levels in the wide open throttle position (WOT) for targeted 500-hour increments (or less). Fuel flow, fuel inlet and outlet temperatures, transfer pump, pump housing pressures, and RPM were tracked and recorded. Flow meter readings reflect the injected fuel from the eight fuel injectors in each collection canister. Any wear in the fuel injection pump metering section was reflected as an increased or reduced flow

reading. For these sets of tests the fuel inlet temperature control target was 77 °C. Fuel inlet temperature variations directly can affect the fuel return temperature; the fuel return temperature is a function of accelerated pump wear. The transfer pump pressure is the regulated pressure the metal blade transfer pump supplies to the pump metering section. With low lubricity fuels, wear is likely to occur in the transfer pump blades, blade slot, and eccentric liner. Wear in these areas generally causes the transfer pump pressure to decrease. However, because the transfer pump has a pressure regulator, significant wear needs to occur in the transfer pump before the fuel pressure drops to below the operating range allowed in the pump specification. The housing pressure is the regulated pressure in the pump body that affects fuel metering and timing. With low lubricity fuel, wear occurs in high fuel pressure generating opposed plungers and bores, and between the hydraulic head and rotor. Leakage from the increased diametrical clearances of the plunger bores and the hydraulic head and rotor, results in increased housing pressures. Increased housing pressure reduces metered fuel and retards injection timing.

4.2 PUMP TEST STAND

The rotary pumps were tested on a drive stand with a common fuel supply. To insure a realistic test environment, the mounting arrangement and drive gear duplicate that of the 6.5LT engine. The fuel was maintained in a 55-gallon drum and continuously recirculated throughout the duration of each test. A gear pump provided a positive head of 3 to 5 psig at the inlet to the test pumps. A cartridge filter rated at 2 microns was used to remove wear debris and particulate contamination. Finally, a 7-kW Chromalox explosion-resistant circulation heater produced the required fuel inlet temperature.

The high-pressure outlets from the pumps were connected to eight Bosch Model O432217276 fuel injectors for a 6.5LT turbocharged engine and assembled in a collection canister. Fuel from both canisters was then returned to the 55-gallon drum. A separate line was used to return excess fuel from the governor housing to the fuel supply. Fuel-to-water heat exchangers on both the return lines from the injector canisters and the governor housing were used to cool the fuel. The test stand with pumps mounted is shown in Figure 3.

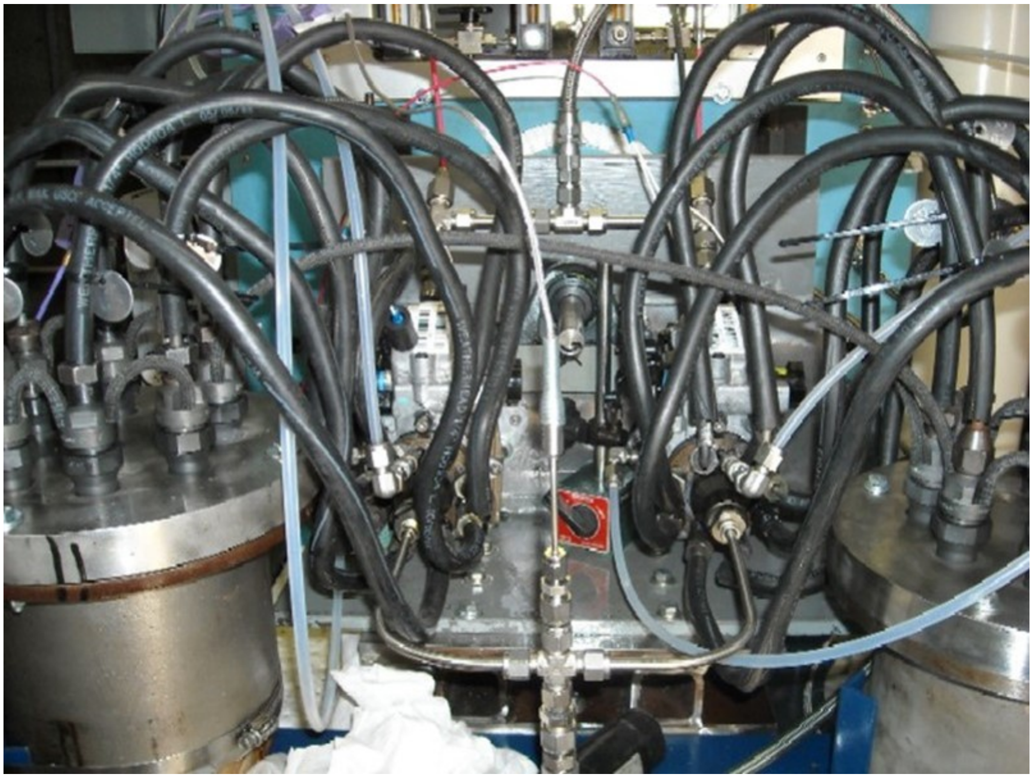


Figure 3. Dual Stanadyne Rotary Fuel Injection Pumps Mounted on Stand with Fuel Injectors

A data acquisition and control system recorded pump stand RPM, fuel inlet pressure, fuel inlet and return temperature, transfer pump pressures, pump housing pressures, and fuel flow readings. The entire rig was equipped with safety shutdowns that would turn off the drive motor in the event of low fluid level in the supply drum, high inlet and return fuel temperature (100 ºC), or low or high transfer pump and housing pressure. Since high-return fuel temperature is a precursor of accelerated wear, this fail-safe feature reduces the possibility of head and rotor seizure.

5.0 ROTARY FUEL INJECTION PUMP EVALUATIONS AND RESULTS

5.1 ROTARY FUEL INJECTION PUMPS WITH ELEVATED TEMPERATURE DSH8/JP-8 FUEL

5.1.1 20/80 DSH8/JP-8 with 9-ppm CI/LI Fuel at 77 °C

Two Stanadyne model DB2831-6282 fuel injection pumps were installed on the test stand and the pumps were operated for an hour to validate their operation and to run-in the components with a good lubricity calibration fluid. The pumps were run for 30-minutes at 1200-RPM pump speed, with a half-rack fuel flow setting. For the final 30-minutes of the run-in the pumps were operated at the test condition of 1700-RPM pump speed, with a full-rack fuel flow setting.

The test bench and pumps were flushed with isooctane to attempt to remove any remaining run-in fluid. The isooctane was forced through the fuel injection pumps with pressure; the pumps were not run with isooctane in them. Following the isooctane flush, the treated DSH8/JP-8 fuel was introduced into the test stand and the stand was operated at an idle condition until 2L of fuel was flushed through each set of eight injectors.

An artifact of the test stand evaluations is that when the governor mechanism lessens the fuel quantity the electric motor does not respond and reduce pump speed as an engine would. It has been noted that with low viscosity fuels at elevated temperatures this interaction causes the fuel injection pumps to rattle. It is felt the pump rattle can cause excessive drive tang wear. Usually the pump rattle can be reduced by lowering the testing speed below the governor interaction point. As wear occurs in the pump, this interaction sometimes also occurs at the lower speed and the test speed is subsequently reduced again. The reduction in test speed on the stand is used as a measure of test fuel performance degradation. Prior to DSH8 blend testing the backlash of the entire stand drive system was investigated to insure backlash in the test stand drive was not influencing pump performance and durability.

The testing with the DSH8/JP-8 fuel with 9-ppm CI/LI was initiated and the fuel injection pumps and stand control system functioned normally. The operating summaries for the respective fuel injection pumps are shown in Table 5, averaged over the 500-hour operating interval for each fuel injection pump.

Table 5. 20/80 DSH8/JP-8 with 9-ppm CI/LI Pump Operating Summary

Parameter	Unit	Average	Std. Dev.
Pump Speed	RPM	1700	1.25
Fuel Inlet Pressure	psig	3.05	0.16
Fuel Inlet Temperature	°C	77.0	0.41
Housing Pressure, SN:17102938	psig	12.87	0.77
Housing Pressure, SN:17102937	psig	13.57	0.48
Transfer Pump Pressure, SN:17102938	psig	73.30	0.57
Transfer Pump Pressure, SN:17102937	psig	66.55	0.49
Pump Fuel Return Temperature, SN:17102938	°C	82.6	0.90
Pump Fuel Return Temperature, SN:17102937	°C	81.6	0.82
Injected Flow Rate, SN:17102938	ml/min	759.6	11.22
Injected Flow Rate, SN:17102937	ml/min	776.8	7.96

The flow histories of the fuel injection pumps operating on the DSH8/JP-8 blend with 9-ppm CI/LI at 77 °C fuel inlet temperature, are shown in Figure 4. From the onset of testing pump SN:17102937 injected delivery was fairly steady during the hours of operation. Pump SN:17102938 exhibited more erratic delivery, with delivery rising initially during testing, with consistent delivery at the end of testing. However both fuel injection pumps were functioning well on the DSH8/JP-8 blend with 9-ppm CI/LI at the conclusion of the 500-Hours of operation.

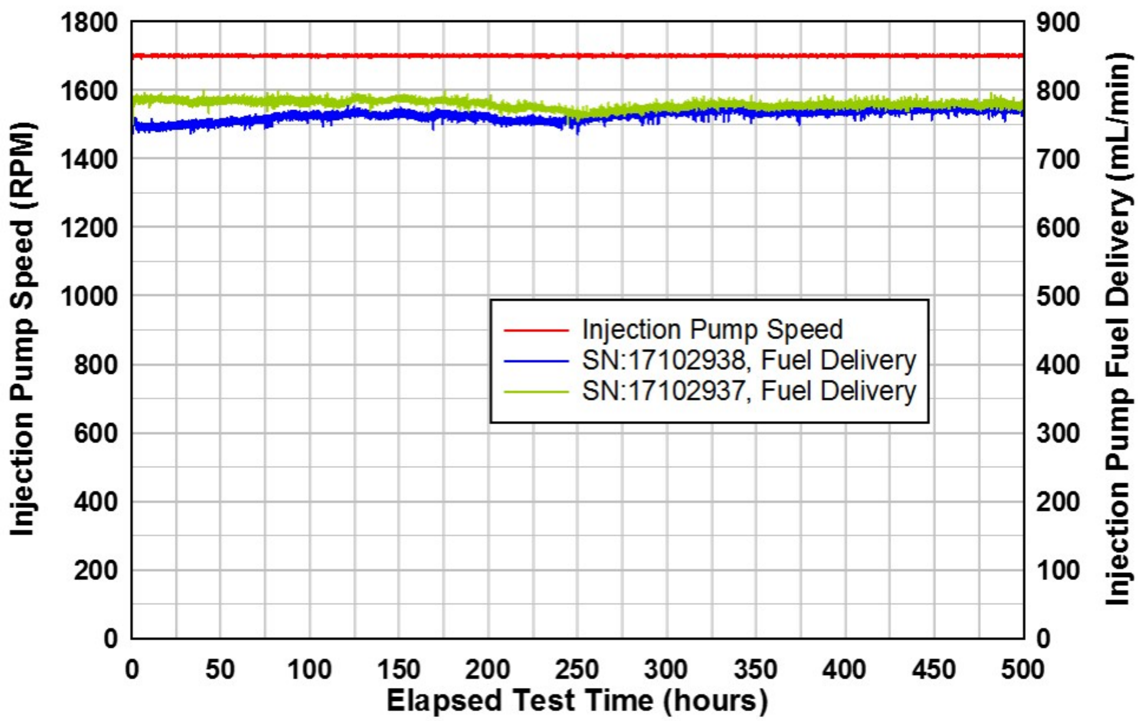


Figure 4. Injection Pump Delivery Histories for 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI Evaluation

The temperature histories of the fuel injection pumps are shown in Figure 5. From the onset of testing both fuel injection pumps exhibited stable fuel return temperature behavior. For pump SN:17102938 the return fuel temperature slightly decreased, then remained consistent towards the end of the test. Pump SN:17102937 exhibited similar behavior. Unusual wear in the pumps usually results in increases and variability of the fuel return temperatures. The fuel inlet temperature to both pumps was very consistent throughout testing.

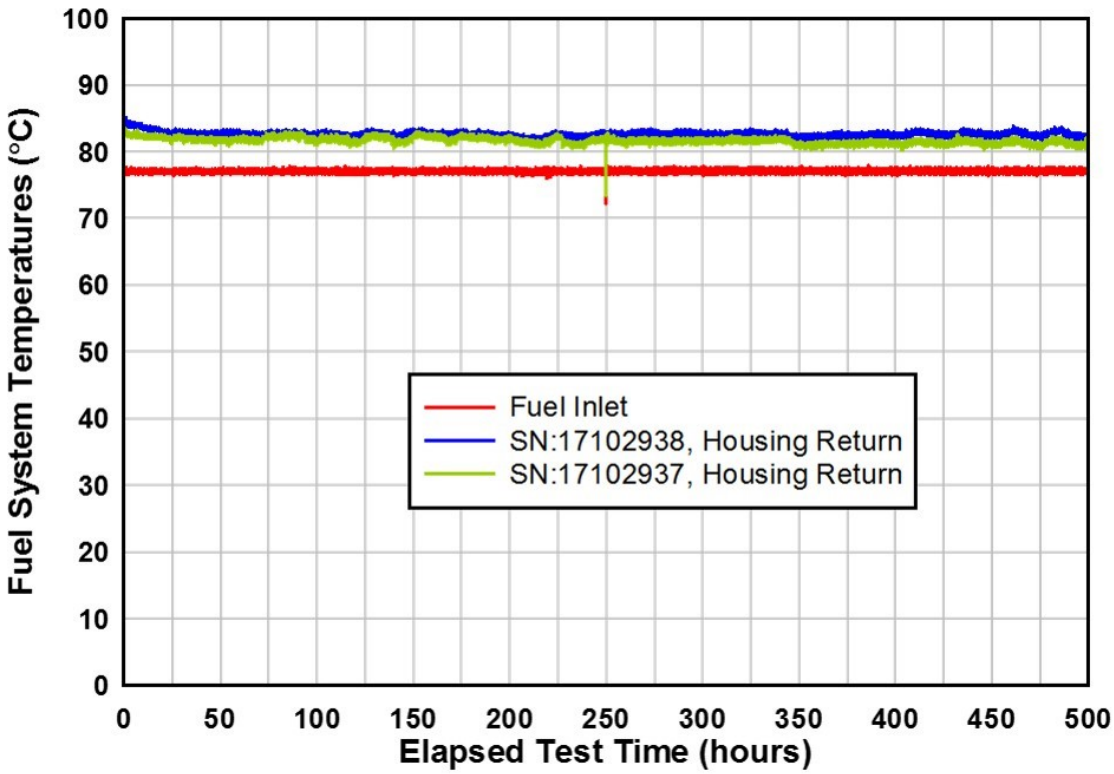


Figure 5. Injection Pump Temperature Histories for 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI Evaluation

Figure 6 shows the fuel pressure histories for the test with the DSH8/JP-8 fuel with 9-ppm CI/LI. The fuel inlet pressure for pumps SN:17102937 and SN:17102938 maintained a consistent level throughout the 500-Hours of operation. Housing pressures for pumps SN:17102937 and SN:17102938 maintained a very slight steady increase throughout the test duration. Housing pressures increase due to leakage from the high pressure section of the pump. The transfer pump pressure for pump SN:17102937 revealed a slight steady increase in pressure for the first 250-

hours, then a fairly steady value towards the end of the test. Pump SN:17102938 reveals a slight decrease over the first 250-hours, then a steady mean value until the end of the test. Any erratic pressure excursions of the transfer pump indicate pump liner, pump blade, and pump regulator wear.

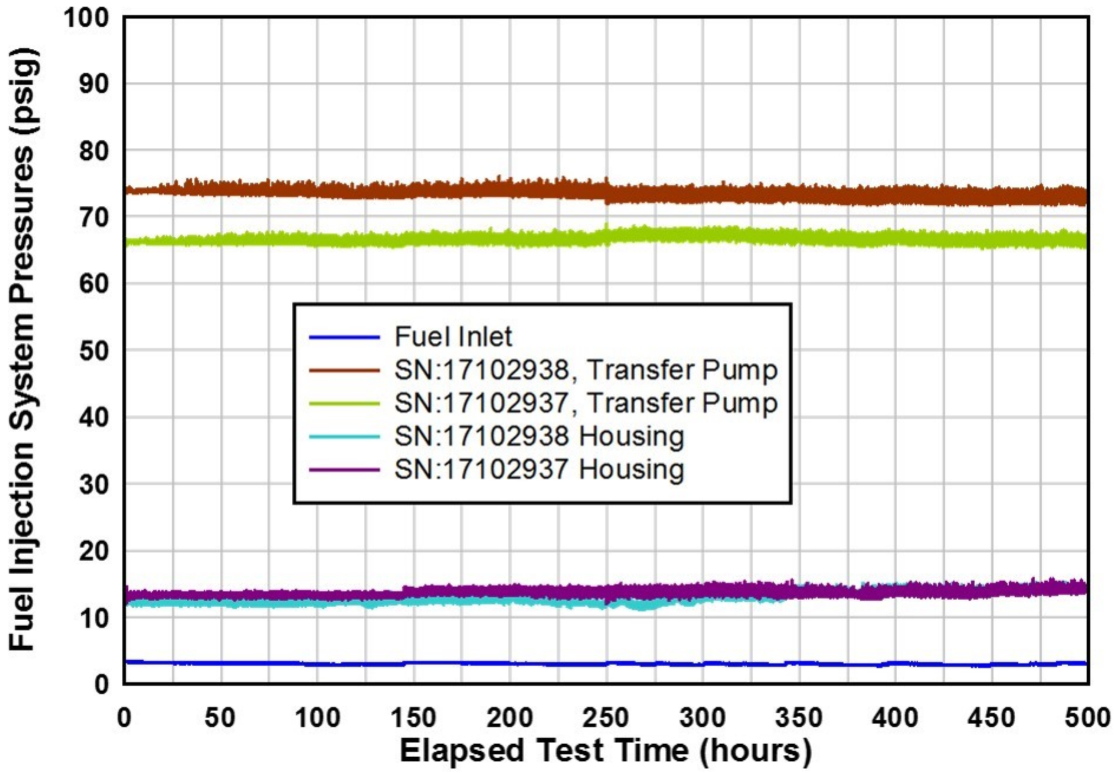


Figure 6. Injection Pump Pressure Histories for 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI Evaluation

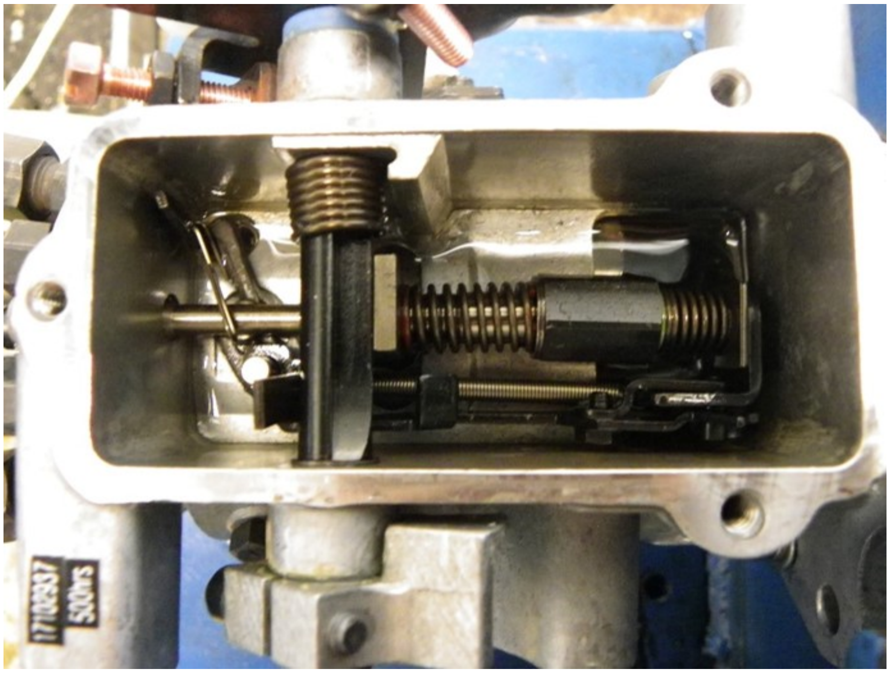


Figure 7. Pump SN:17102937 Governor Assembly with 500-Hours Testing with DSH8/JP-8 Fuel

At 500-Hours of testing the tops of both fuel injection pumps were removed for inspection of wear debris. The housing for pump SN:17102937 is shown in Figure 7 and there is not any wear debris or housing staining evident. The housing for pump SN:17102938 is shown in Figure 8, for which wear debris is also not evident, but there is very light amber staining of the housing.

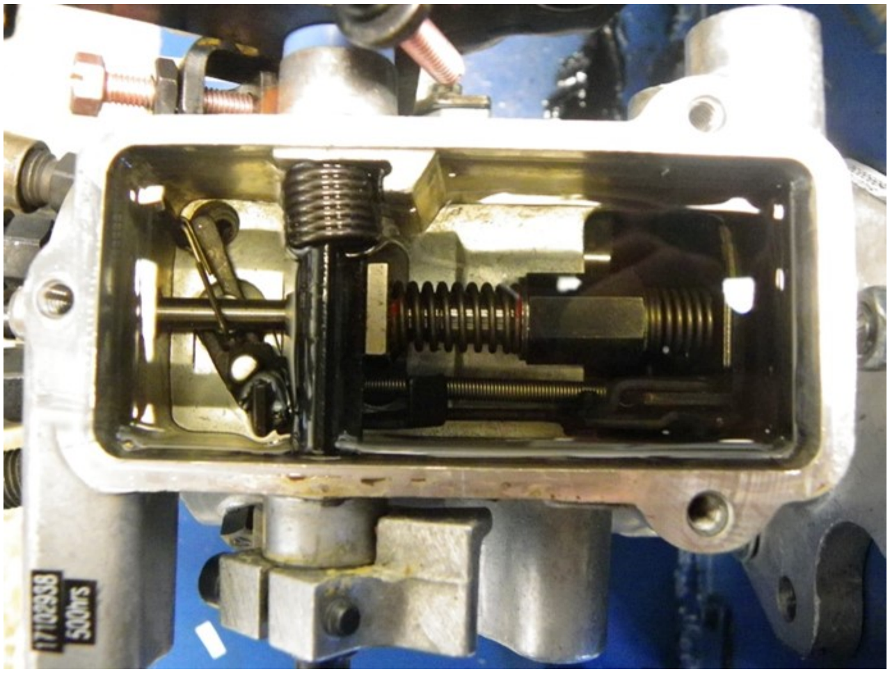


Figure 8. Pump SN:17102938 Governor Assembly with 500-Hours Testing with DSH8/JP-8 Fuel

5.2 ROTARY PUMP PERFORMANCE MEASUREMENTS

Prior to the durability testing all the fuel injection pumps were run on an injection pump calibration stand to verify their performance with respect to their model number and application specification sheet. Although the pumps came from the factory set to meet their designated specification, because SwRI disassembles the pumps to take transfer pump blade measurements and roller-to-roller dimensions the fuel injection pumps performance is validated by this pre-test calibration. At the conclusion of testing the fuel injection pumps were installed on the calibration stand and checked for performance changes due to the test fuel. There were not any adjustments made to the fuel injection pumps by the calibration personnel nor was the pump disassembled prior to completion of this calibration.

5.2.1 20/80 DSH8/JP-8 with 9-ppm CI/LI Fuel at 77 °C

The Pre- and Post-Test performance curves for fuel injection pump SN:17102937 are included as Table 6. Items in colored **bold** text in Table 6 are values that fall outside of the specification for the fuel injection pump model. **Red** bold text is for values below the specification minimums. **Blue** bold text is for values above the specification maximums. At the start of testing, the 900-RPM

delivery quantity were just slightly above the specification maximum. At the end of testing the delivery characteristics at 900-RPM did not change. At low idle, 350-RPM, pump SN:17102937 was above the maximum delivery value that could result in a fast engine idle. The results at 1975-RPM suggest that governor operation has been compromised for the SN:17102937 pump on the DSH8/JP-8 fuel blend with 9-ppm CI/LI. The minimum delivery value at 75-RPM was met, so engine starting with this pump would not be an issue. The proper delivery at 200-RPM indicates the engine would run-up to idle speed satisfactorily.

The Pre- and Post-Test performance curves for fuel injection pump SN:17102938 are included as Table 7. At the start of testing, the 900-RPM delivery quantity was slightly below the specification maximum. At the end of testing the delivery at 900-RPM increased to just slightly above the maximum specification, so peak engine torque would be adequate. The elevated delivery at 1975-RPM suggest that governor operation has been compromised for the SN:17102938 pump on the DSH8/JP-8 fuel blend with 9-ppm CI/LI. The minimum delivery value at 75-RPM was met, so engine starting with this pump would not be an issue. The proper delivery at 200-RPM indicates the engine would run-up to idle speed satisfactorily.

Both fuel injection pumps completed 500-Hours of operation at elevated temperature with the DSH8/JP-8 fuel with 9-ppm CI/LI. Both pumps exhibited some performance degradation with respect to their calibration performance criterion in the operation of governor over-speed protection.

Table 6. Injection Pump SN:17102937 Performance Specifications

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-6282 (arctic)	**SN : 17102937**
Test condition : 500 hours @ FIT 77°C and 1700 RPM	**Test : CAF9316-20-C3DSH1-77-500**
Fuel : 20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316	

PUMP RPM	***Description***	***Specification***		***Pump Duration: 500 Hours***		
		min.	***max.***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60 psi	62 psi	62 psi	64 psi	-2 psi
	Return Fuel	225 cc	375 cc	340 cc	325 cc	15 cc
350	Low Idle	12 cc	16 cc	16.0 cc	20.0 cc	-4.0 cc
	Housing psi.	8 psi	12 psi	10.0 psi	11.0 psi	-1.0 psi
	Advance	3.5°		5.7°	5.8°	-.1°
	Cold Advance Solenoid	0 psi	1 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4 cc	0 cc	0 cc	0 cc
900	Fuel Delivery	64.5 cc	67.5 cc	68.0 cc	68.0 cc	.0 cc
1600	WOT Fuel delivery	58.5 cc		62.0 cc	62.0 cc	.0 cc
	WOT Advance	2.5°	3.5°	3.0°	3.0°	.0°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	23.0 cc	23.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.9°	6.9°	.0°
	Low Idle	11.0°	12.0°	11.0°	11.0°	.0°
1700	WOT Fuel Delivery	58 cc		63.0 cc	64.0 cc	-1.0 cc
1850	Fuel Delivery	33 cc		38.0 cc	60.0 cc	-22.0 cc
1975	High Idle		15 cc	10 cc	30 cc	20 cc
	Transfer pump psi.		125 psi	100 psi	96 psi	4.0 psi
200	WOT Fuel Delivery	58 cc		60.0 cc	64.0 cc	-4.0 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		50.0 cc	50.0 cc	.0 cc
	Transfer pump psi.	16 psi		21.0 psi	23.0 psi	-2.0 psi
	Housing psi.	0 psi	12 psi	10.0 psi	10.0 psi	.0 psi
	Air Timing	-1.0°	0°	-.5°	-.5°	.0°
	Fluid Temp. Deg. C :			41.8°	42.0°	
	Date :			11/6/2015	1/7/2016	

Notes :

Table 7. Injection Pump SN:17102938 Performance Specifications

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-6282 (arctic)	SN : 17102938
Test condition : 500 hours @ FIT 77°C and 1700 RPM	Test : CAF9316-20-C3DSH1-77-500
Fuel : 20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316	

PUMP RPM	Description	Specification min.	Specification max.	Pump Duration: 500 Hours Before	Pump Duration: 500 Hours After	Pump Duration: 500 Hours Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	64 psi	-2 psi
	Return Fuel	225 cc	375 cc	300 cc	300 cc	0 cc
350	Low Idle	12 cc	16 cc	14.0 cc	16.0 cc	-2.0 cc
	Housing psi.	8 psi	12 psi	10.0 psi	11.5 psi	-1.5 psi
	Advance	3.5°		5.4°	5.5°	-.1°
	Cold Advance Solenoid	0 psi	1 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4 cc	0 cc	0 cc	0 cc
900	Fuel Delivery	64.5 cc	67.5 cc	64.0 cc	68.0 cc	-4.0 cc
1600	WOT Fuel delivery	58.5 cc		60.0 cc	64.0 cc	-4.0 cc
	WOT Advance	2.5°	3.5°	3.1°	2.5°	.6°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	23.0 cc	24.0 cc	-1.0 cc
	Face Cam Advance	5.25°	7.25°	6.3°	6.3°	.0°
	Low Idle	11.0°	12.0°	11.0°	11.0°	.0°
1700	WOT Fuel Delivery	58 cc		60.0 cc	64.0 cc	-4.0 cc
1850	Fuel Delivery	33 cc		38.0 cc	48.0 cc	-10.0 cc
1975	High Idle		15 cc	4 cc	20 cc	16 cc
	Transfer pump psi.		125 psi	104 psi	101 psi	3.0 psi
200	WOT Fuel Delivery	58 cc		58.0 cc	64.0 cc	-6.0 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		48.0 cc	50.0 cc	-2.0 cc
	Transfer pump psi.	16 psi		24.0 psi	24.0 psi	.0 psi
	Housing psi.	0 psi	12 psi	10.0 psi	11.0 psi	-1.0 psi
	Air Timing	-1.0°	0°	-.5°	-.5°	.0°
	Fluid Temp. Deg. C :			41.8°	42.0°	
	Date :			11/6/2015	1/7/2016	

Notes :

5.3 ROTARY PUMP WEAR MEASUREMENTS

The transfer pump and plunger assemblies are integral to the fuel-metering system in the Stanadyne rotary pump, and by function are the most affected by low lubricity fuel. Accelerated wear in either the transfer pump blades or the roller-to-roller dimension results in a change of fueling condition that jeopardizes the quantity of fuel injected into the hydraulic head assembly. Wear in the transfer pump blades limits the amount of pressure necessary to maintain the proper amount of fuel in the chamber where opposing plungers, actuated by the rollers and cam, inject the metered fuel into the hydraulic head assembly. Roller-to-roller dimension variations alter the travel distance of the plungers, effectively changing metered fuel, injection pressure, and injection timing.

5.3.1 20/80 DSH8/JP-8 with 9-ppm CI/LI Fuel at 77 °C

Table 8 and Table 9 present the transfer pump blade and roller-to-roller dimension measurement results for the two fuel injection pumps that operated on the DSH8/JP-8 fuel blend with 9-ppm CI/LI at elevated temperature. There were not any out-of-specification transfer blade measurements based on the dimension length C for either pump SN:17102937 or SN:17102938. The width of the blades did not change dramatically, nor did the blade’s thicknesses decrease much. Both pump SN:17102937 and pump SN:17102938 roller-to-roller dimensions increased slightly, however changing less than the ±0.127-mm assembly specification tolerance. The slight roller-to-roller dimensions increase for both pumps is reflected in the stable delivery seen for both pumps during testing. The roller-to-roller eccentricity specification is 0.2032-mm maximum, which neither pump SN:17102937 or pump SN:17102938 approached after 500-Hours testing with the DSH8/JP-8 fuel blend with 9-ppm CI/LI. In general all transfer pump blades were in fair condition, and the minimal roller-to-roller dimensions changes reflected the minimal performance changes seen on the test stand.

Table 8. Pump SN:17102937 Blade Size Measurements

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-6282	SN: 17102937	Test Number : CAF9316-20-C3DSH1-77-500
Fuel description : 20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316		

	Date:	9/20/2015	2/8/2016	
Dimensional Measurements (mm)		***0 hrs.***	***500 hrs.***	***Change***
Transfer Pump Blade 1	Dimension A	13.7973	13.7719	-0.0254
	Dimension B	9.8908	9.8641	-0.0267
	Dimension C	12.6746	12.6746	0.0000
	Dimension D	3.1229	3.1217	-0.0013
	Dimension E	3.1217	3.1204	-0.0013
	Dimension F	3.1217	3.1179	-0.0038
Transfer Pump Blade 2	Dimension A	13.7998	13.7795	-0.0203
	Dimension B	9.8870	9.8666	-0.0203
	Dimension C	12.6746	12.6721	-0.0025
	Dimension D	3.1179	3.1179	0.0000
	Dimension E	3.1166	3.1153	-0.0013
	Dimension F	3.1179	3.1166	-0.0013
Transfer Pump Blade 3	Dimension A	13.7909	13.7668	-0.0241
	Dimension B	9.8870	9.8704	-0.0165
	Dimension C	12.6746	12.6721	-0.0025
	Dimension D	3.1166	3.1166	0.0000
	Dimension E	3.1166	3.1145	-0.0020
	Dimension F	3.1166	3.1140	-0.0025
Transfer Pump Blade 4	Dimension A	13.7960	13.7719	-0.0241
	Dimension B	9.8806	9.8628	-0.0178
	Dimension C	12.6683	12.6670	-0.0013
	Dimension D	3.1191	3.1179	-0.0013
	Dimension E	3.1179	3.1166	-0.0013
	Dimension F	3.1191	3.1166	-0.0025
	Roller to Roller (mm)	50.2158	50.2590	0.0432
	Eccentricity (mm)	0.1270	0.1270	0.0000
	Drive Backlash (mm)	0.1270	0.1524	0.0254

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Inches	0.4986	0.4993
Millimeters	12.66444	12.68222

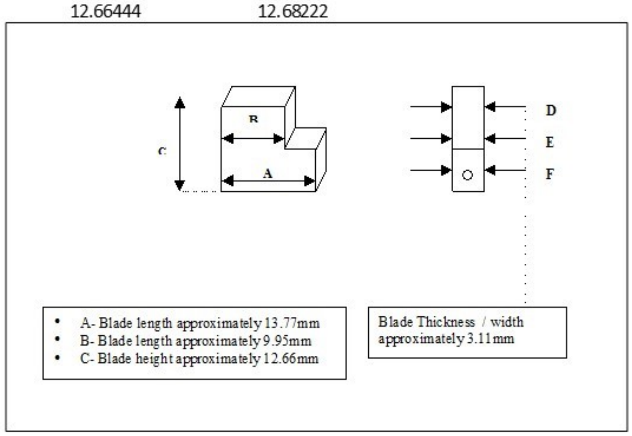


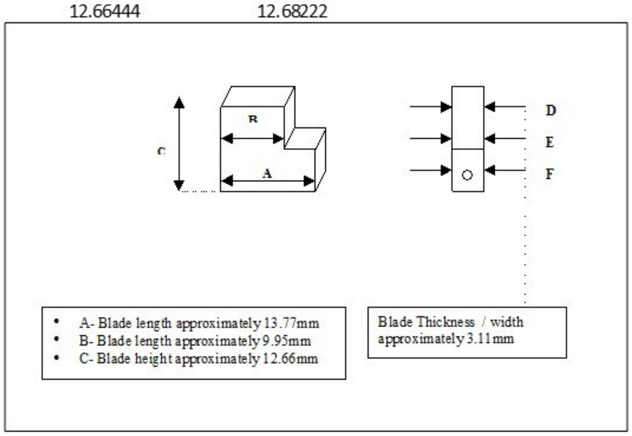
Table 9. Pump SN:17102938 Blade Size Measurements

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-6282	SN: 17102938	Test Number : CAF9316-20-C3DSH1-77-500
Fuel description : 20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316		

Dimensional Measurements (mm)	Date:	9/20/2015	2/9/2016	
		0 hrs.	**500 hrs.**	**Change**
Transfer Pump Blade 1	Dimension A	13.7973	13.7528	-0.0444
	Dimension B	9.8717	9.8323	-0.0394
	Dimension C	12.6683	12.6670	-0.0013
	Dimension D	3.1191	3.1179	-0.0013
	Dimension E	3.1191	3.1166	-0.0025
	Dimension F	3.1191	3.1166	-0.0025
Transfer Pump Blade 2	Dimension A	13.8024	13.7566	-0.0457
	Dimension B	9.8857	9.8450	-0.0406
	Dimension C	12.6683	12.6670	-0.0013
	Dimension D	3.1267	3.1242	-0.0025
	Dimension E	3.1255	3.1242	-0.0013
	Dimension F	3.1242	3.1229	-0.0013
Transfer Pump Blade 3	Dimension A	13.7947	13.7503	-0.0444
	Dimension B	9.8844	9.8400	-0.0444
	Dimension C	12.6708	12.6708	0.0000
	Dimension D	3.1179	3.1179	0.0000
	Dimension E	3.1179	3.1166	-0.0013
	Dimension F	3.1179	3.1166	-0.0013
Transfer Pump Blade 4	Dimension A	13.7947	13.7503	-0.0444
	Dimension B	9.8844	9.8463	-0.0381
	Dimension C	12.6721	12.6721	0.0000
	Dimension D	3.1255	3.1255	0.0000
	Dimension E	3.1255	3.1242	-0.0013
	Dimension F	3.1255	3.1229	-0.0025
	Roller to Roller (mm)	50.1650	50.1904	0.0254
	Eccentricity (mm)	0.0762	0.0762	0.0000
	Drive Backlash (mm)	0.1016	0.1778	0.0762

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Inches	0.4986	0.4993
Millimeters	12.66444	12.68222



5.4 FUEL INJECTOR RESULTS

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5LT diesel engine manual using diesel nozzle tester J 29075B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1,500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1,400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required.

New Bosch Model O432217276 injectors were used for both pumps for the fuel test. The injector performance tests and rating results are shown in Table 10 for the DSH8/JP-8 test with 9-ppm CI/LI at elevated temperature. All sixteen fuel injectors passed the post-test opening pressure evaluations. All sixteen fuel injectors passed the injector tip leakage, chatter, and spray pattern checks.

Table 10. Fuel Injector Performance Evaluations after 500-Hours DSH8/JP-8 with 9-ppm CI/LI Fuel Usage

Stanadyne Rotary Pump Lubricity Evaluation
6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure (pre-test)	Opening Pressure (post-test)	Tip Leakage (pre-test)	Tip Leakage (post-test)	Chatter (pre-test)	Chatter (post-test)	Spray pattern (pre-test)	Spray pattern (post-test)	Date (pre-test)	Date (post-test)	Test Hours	Tech.
CAF9316-20-C3DSH1-77-500	SN : 17102937	20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316	DSH1-1	2175	2000	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-2	2125	1925	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-3	2125	1825	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-4	2100	1850	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-5	2175	1925	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-6	2100	1900	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-7	2152	1925	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-8	2100	1950	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
CAF9316-20-C3DSH1-77-500	SN : 17102938	20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316	DSH1-9	2100	1800	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-10	2100	1875	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-11	2125	1925	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-12	2100	1900	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-13	2125	1800	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-14	2100	1875	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-15	2125	1875	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			DSH1-16	2100	1925	pass	pass	pass	pass	pass	pass	10/19/2015	1/10/2016	500	REG
			Spec. :	1500psig min	1500psig min	no drop off in 10 sec. @ 1400 psi	no drop off in 10 sec. @ 1400 psi	chatter	chatter	fine mist	fine mist				

Comments :

5.5 Rotary Pump Component Wear Evaluations

After the fuel injection pump calibration and functional performance checks, the fuel injection pumps were disassembled and the components critical to pump operation were evaluated for parts conditions. A technician with over twenty five years of experience rebuilding, servicing, and testing Stanadyne fuel injection pumps performed the subjective wear ratings.

5.5.1 20/80 DSH8/JP-8 with 9-ppm CI/LI Fuel Blend at 77 °C – Pump SN:17102937

The parts conditions and subjective wear ratings for fuel injection pump SN:17102937 are summarized in Table 11. Images of the wear seen on the components of fuel injection pump SN:17102937 are shown in Figure 9 through Figure 26. Figure 9 and Figure 10 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure 10 shows the discharge ports and rotor are in good condition, with very light circumferential scratching from wear debris after 500-Hours with DSH8/JP-8 fuel with 9-ppm CI/LI at elevated temperature.

Figure 11 and Figure 12 is the Pre-Test and Post-Test conditions of the fuel injection pump SN:17102937 roller shoe and roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure 11. Figure 12 reveals mild wear scars on the roller shoe from the leaf spring contact and heavy burnishing of the rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. The roller shoe and pumping plunger contacts are shown in Figure 13 and Figure 14 that show a relatively mild wear scar on one roller shoe, and moderate wear on the other shoe due to 500-Hours operation. The injection pump cam ring shown in Figure 15 and Figure 16 reveals polishing, scratching, and light scuffing wear on the cam lobes with the 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI blend.

The governor thrust washer condition before and after 500-Hours is seen in Figure 17 and Figure 18. The polishing wear seen on the thrust washer in Figure 18 is typical for the 500-hour operating interval. Polishing and fuel deposition wear seen on the advance piston, suggesting there were fuel pressure fluctuations in that area of the fuel injection pump housing. The metering valve regulates

the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a lightly polished area shows at one location on the helix. The light wear on these components is normal considering the 500-hour duration of testing. The wear on the thrust washer, the advance piston wear, and the metering valve did not have an effect on pump operation.

Figure 19 and Figure 20 illustrates the level of wear seen in the transfer pump section of fuel injection pump SN:17102937. Figure 19 shows the surface condition of the transfer pump liner prior to testing and Figure 20 shows the surface with heavy 95% circumferential scarring after 500-Hours of operation on the 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figure 21 through Figure 24. The edge wear shown in Figure 21 and Figure 22 corresponds to the surface on the transfer pump blades that contact the transfer pump liner, and they reveal moderate scoring. The side polishing shown in Figure 23 and Figure 24 reflect wear from the transfer pump blade slots on the injection pump rotor. The transfer pump component conditions suggest the test fuel has marginal fuel lubricity.

Figure 25 and Figure 26 show the condition of the injection pump drive shaft drive tang that transmits torque to the hydraulic section of the pump from the engine. Figure 26 reveals a minor wear scar that indicates backlash and timing were not altered with the 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI blend after 500-Hours at elevated 77 °C fuel inlet temperature.

Table 11. Pump SN:17102937 Component Wear Ratings

Stanadyne Pump Parts Evaluation

Pump Type : DB2831-6282	SN : 17102937
Test condition : 500 hours @ FIT 77°C and 1700 RPM	TEST : CAF9316-20-C3DSH1-77-500
Fuel : 20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316	

Part Name	Condition of part	Rating 0 = New 5 = Failed
BLADES	Brown deposits, wear from liner contact, rotor slots, & regulator	2.5
BLADE SPRINGS	polishing wear	1.5
LINER	95% scorring	4
TRANSFER PUMP REGULATOR	Polishing wear from blades & rotor, brown deposits	2
REGULATOR PISTON	Light polishing	1
ROTOR	Wear lines around both ports, inlet & outlet	2.5
ROTOR RETAINERS	Brown deposits, wear from rotor	2.5
DELIVERY VALVE	Light polishing wear	1.5
PLUNGERS	Polishing wear	2
SHOES	Light wear from leaf spring and plungers, mild scratches from rollers	2
ROLLERS	Discoloration, no visible scarring	1.5
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Polishing wear on lobes	1.5
THRUST WASHER	Polishing wear from both weights and sleeve.	2
THRUST SLEEVE	Wear from linkage hook fingers & thrust washer	2
GOVERNOR WEIGHTS	Light polishing wear from thrust washer contact	1
LINK HOOK	Wear on fingers, arm, & hook connection, dimple on pivot spots	2.5
METERING VAVLE	Polishing wear	1.5
DRIVE SHAFT TANG	Light wear from rotor slot contact	1.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Light polishing, in specification	1
ADVANCE PISTON	Brown deposits located on polished areas	2
HOUSING	Light golden brown color inside, drive end.	1
AVERAGE DEMERIT RATINGS		1.80

Figure 9. Pump SN:17102937 Distributor Rotor before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

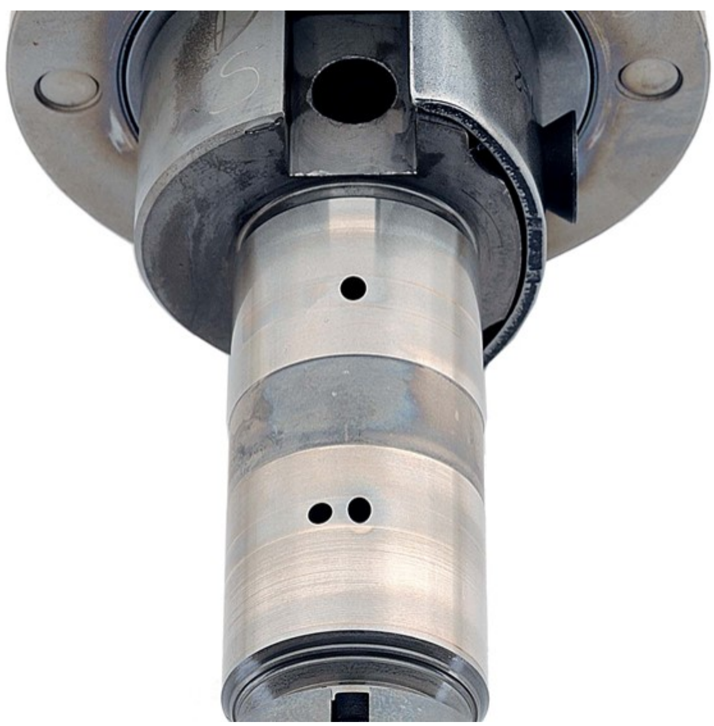


Figure 10. Pump SN:17102937 Distributor Rotor with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 11. Pump SN:17102937 Rollers and Shoe before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 12. Pump SN:17102937 Rollers and Shoe with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 13. Pump SN:17102937 Roller Shoe before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 14. Pump SN:17102937 Roller Shoe with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 15. Pump SN:17102937 Cam Ring before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 16. Pump SN:17102937 Cam Ring with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 17. Pump SN:17102937 Thrust Washer before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 18. Pump SN:17102937 Thrust Washer with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 19. Pump SN:17102937 Transfer Pump Liner before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 20. Pump SN:17102937 Transfer Pump Liner with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 21. Pump SN:17102937 Transfer Pump Blade Edges before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 22. Pump SN:17102937 Transfer Pump Blade Edges with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 23. Pump SN:17102937 Transfer Pump Blade Sides before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

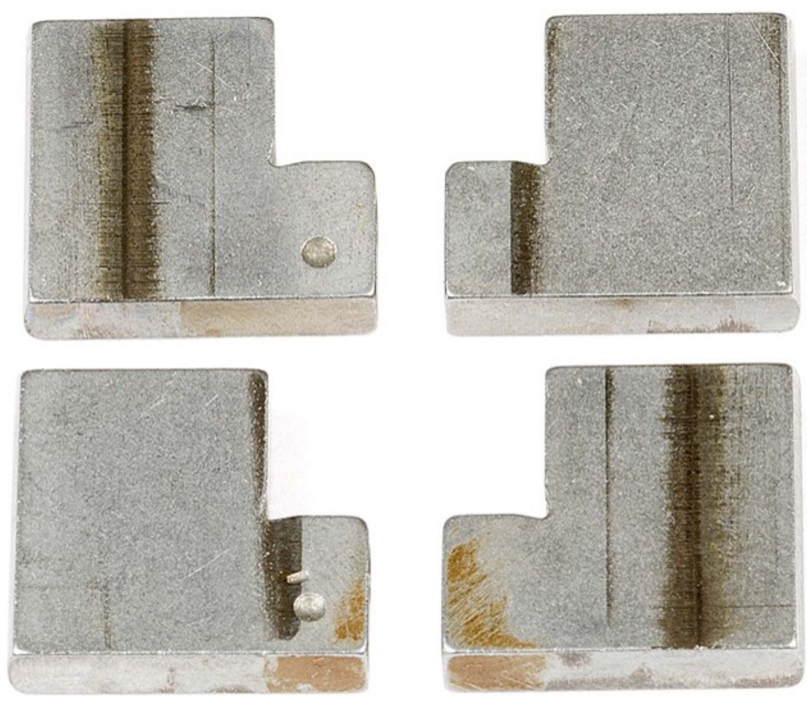


Figure 24. Pump SN:17102937 Transfer Pump Blade Sides with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 25. Pump SN:17102937 Driveshaft Drive Tang Sides before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

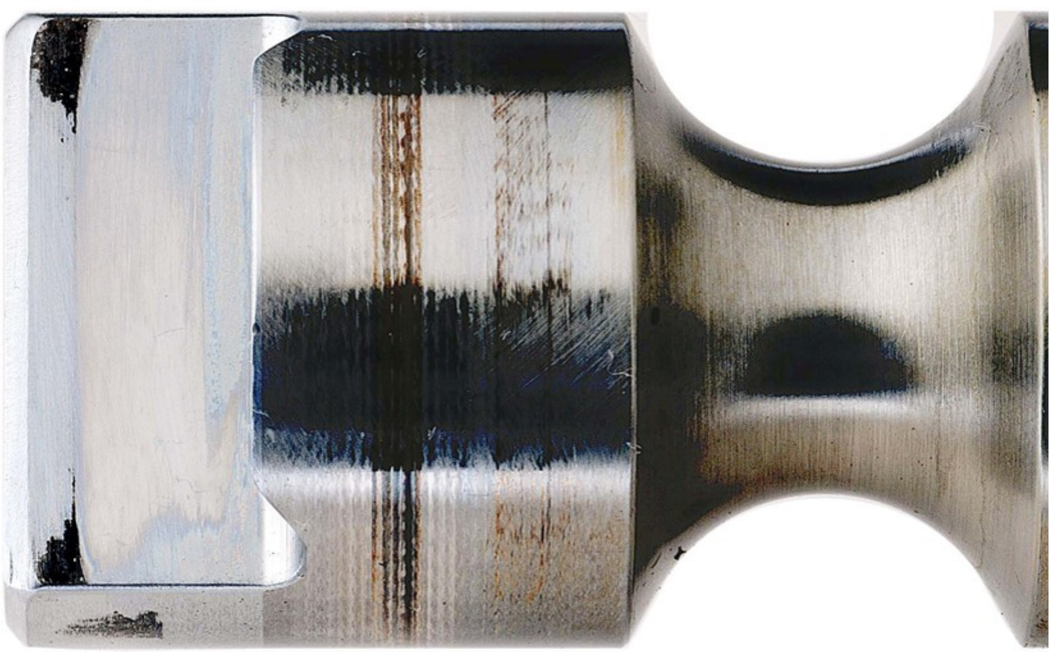


Figure 26. Pump SN:17102937 Driveshaft Drive Tang with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

5.5.2 20/80 DSH8/JP-8 with 9-ppm CI/LI Fuel Blend at 77 °C – Pump SN:17102938

The parts conditions and subjective wear ratings for fuel injection pump SN:17102938 are summarized in Table 12. Images of the wear seen on the components of fuel injection pump SN:17102938 are shown in Figure 27 through Figure 44. Figure 27 and Figure 28 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure 28 shows the discharge ports and rotor with light circumferential scratches and wear near the rotor discharge ports, from wear debris, after the 500-Hours of operation. There also appears to be a small chip missing from the edge of the lower right port..

Figure 29 and Figure 30 is the Pre-Test and Post-Test conditions of fuel injection pump SN:17102938 roller shoe and roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure 29. Figure 30 reveals light wear scars on the roller shoe from the leaf spring contact and burnishing of the rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. Figure 31 and Figure 32 show the moderate to heavy wear scar due to 500-Hours operation at the roller shoe plunger contact. The wear seen in Figure 32 is typical for a marginal lubricity fuel.

The injection pump cam ring shown in Figure 33 and Figure 34 does reveal some polishing wear on the cam lobes from the rollers after 500-Hours operation with the DSH8/JP-8 fuel blend. The roller and cam distress with the DSH8/JP-8 blend with 9-ppm CI/LI is similar to what is typically seen with JP-8 with 22.5-ppm CI/LI after 500-Hours with 77 °C fuel inlet temperature.

The governor thrust washer conditions before and after 500-Hours are seen in Figure 35 and Figure 36. The polishing wear seen on the thrust washer in Figure 36 appears typical for 500-hour operation with a nominal lubricity fuel. Fuel deposition, polishing and light scoring wear seen on the advance piston suggests the fuel pressure fluctuations in that area of the fuel injection pump housing. The metering valve regulates the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a lightly polished area shows at one location on the helix. The light wear on these components is normal

considering the 500-hour duration of testing. The advance piston wear and the metering valve polishing may have affected the governor cut-off operation.

Figure 37 through Figure 42 illustrate the level of wear seen in the transfer pump section of fuel injection pump SN:17102938. Figure 37 shows the surface condition of the transfer pump liner prior to testing and Figure 38 shows the surface with 95% circumferential scoring after 500-Hours of operation on the DSH8/JP-8 fuel with 9-ppm CI/LI. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figure 39 through Figure 42. The edge wear shown in Figure 39 and Figure 40 corresponds to the surface on the transfer pump blades that contact the transfer pump liner and are typical for 500-Hours operation with a marginal lubricity fuel. The side polishing shown in Figure 41 and Figure 42 reflect wear from the transfer pump blade slots on the injection pump rotor. The wear seen on the transfer pump components of pump SN:17102938 are slightly more severe than an elevated temperature JP-8 test with 25-ppm CI/LI treatment. The transfer pump component conditions suggest the test fuel has marginal fuel lubricity at elevated temperature.

Figure 43 and Figure 44 show the condition of the injection pump drive shaft drive tang that transmits torque to the hydraulic section of the pump from the engine. Figure 44 reveals a minimal wear scar that indicates backlash and timing were not altered with the DSH8/JP-8 fuel with 9-ppm CI/LI after 500-Hours. For both pumps that utilized the DSH8/JP-8 with 9-ppm CI/LI fuel, the worn components that impacted the injection pump performance variation were the roller and cam contact, and the transfer pump wear. Both pumps exhibited stable performance after 500-Hours at elevated temperature with the 20/80 DSH8/JP-8 fuel with 9-ppm CI/LI. Pump performance degradation at 500-Hours was more severe than seen with a JP-8 with 22.5-ppm CI/LI at elevated temperature.

Table 12. Pump SN:17102938 Component Wear Ratings

Stanadyne Pump Parts Evaluation

Pump Type : DB2831-6282	SN : 17102938
Test condition : 500 hours @ FIT 77°C and 1700 RPM	TEST : CAF9316-20-C3DSH1-77-500
Fuel : 20% DSH8/80% JP8, 9-ppm CI/LI, CAF-9316	

Part Name	Condition of part	Rating 0 = New 5 = Failed
BLADES	Brown deposits, wear from liner, rotor slots, & regulator contacts	2.5
BLADE SPRINGS	One spring broken	5
LINER	95% heavy scorring	4
TRANSFER PUMP REGULATOR	Heavy brown deposits, deep wear scar from rotor.	3
REGULATOR PISTON	Light scuffing & heavy polishing	2.5
ROTOR	Wear lines around both ports, inlet & outlet	2.5
ROTOR RETAINERS	Brown deposits, wear from rotor	2.5
DELIVERY VALVE	Heavy polishing wear	2
PLUNGERS	Polishing & light scuffing	2.5
SHOES	Light wear from leaf spring and plungers, mild scratches from rollers	2.5
ROLLERS	Discoloration, no visible scarring	1.5
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Polishing wear on lobes	1.5
THRUST WASHER	Polishing wear from both weights and sleeve.	2
THRUST SLEEVE	Wear from linkage hook fingers & thrust washer	2
GOVERNOR WEIGHTS	Polishing wear from thrust washer contact	1.5
LINK HOOK	Wear on fingers, arm, & hook connection, dimple on pivot spots	2.5
METERING VAVLE	Polishing wear	1
DRIVE SHAFT TANG	Light wear from rotor slot contact	1.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Light polishing, in specification	1
ADVANCE PISTON	Brown deposits located on polished areas	2
HOUSING	Light golden brown color inside, drive end.	1
AVERAGE DEMERIT RATINGS		2.13

Figure 27. Pump SN:17102938 Distributor Rotor before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 28. Pump SN:17102938 Distributor Rotor with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 29. Pump SN:17102938 Rollers and Shoe before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 30 Pump SN:17102938 Rollers and Shoe with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 31. Pump SN:17102938 Roller Shoe before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 32. Pump SN:17102938 Roller Shoe with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 33. Pump SN:17102938 Cam Ring before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

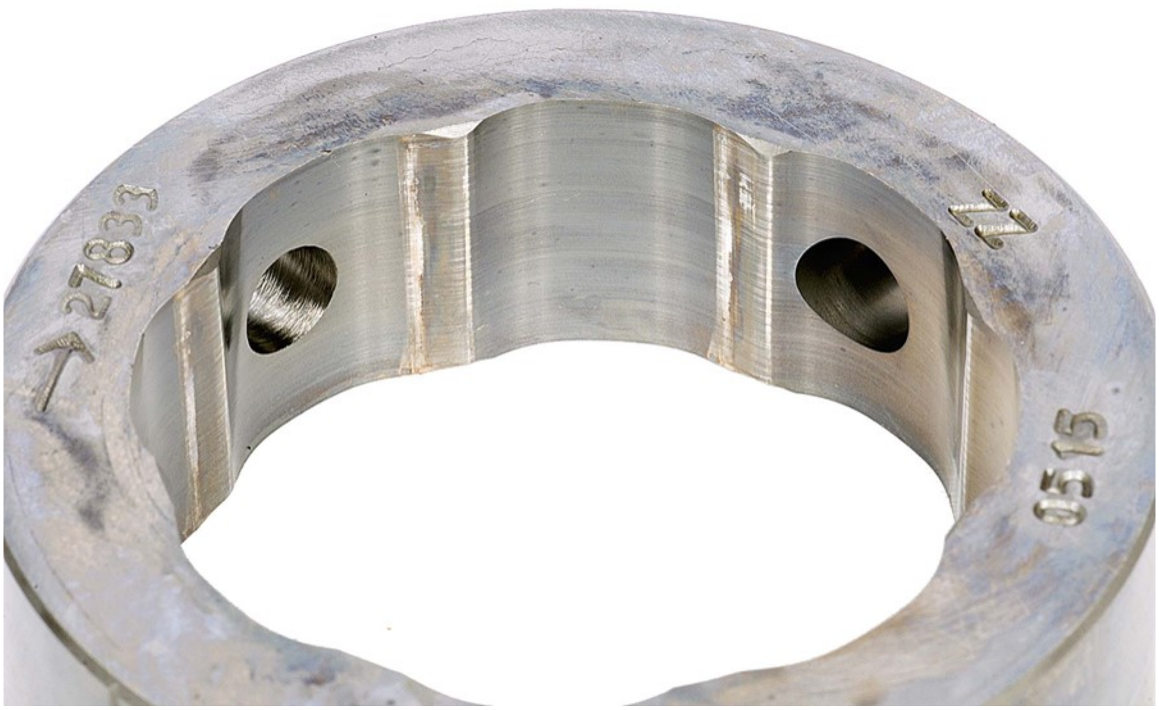


Figure 34. Pump SN:17102938 Cam Ring with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 35. Pump SN:17102938 Thrust Washer before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 36. Pump SN:17102938 Thrust Washer with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 37. Pump SN:17102938 Transfer Pump Liner before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 38. Pump SN:17102938 Transfer Pump Liner with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 39. Pump SN:17102938 Transfer Pump Blade Edges before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 40. Pump SN:17102938 Transfer Pump Blade Edges with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 41. Pump SN:17102938 Transfer Pump Blade Sides before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

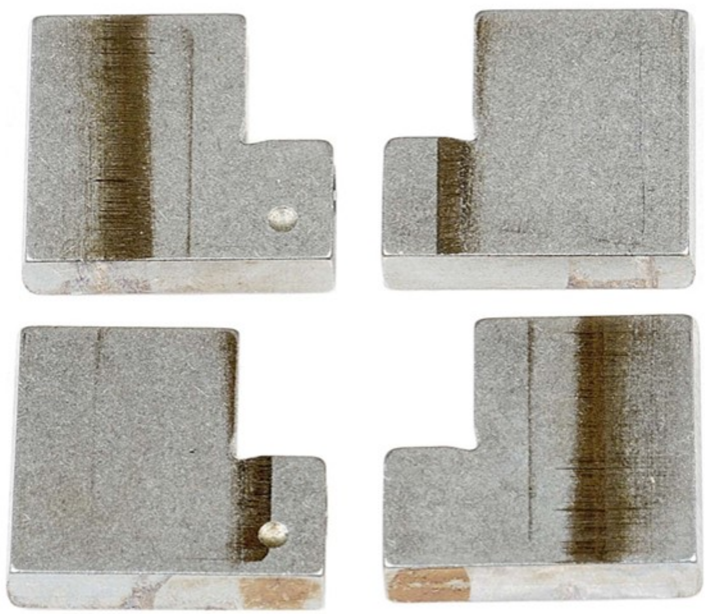


Figure 42. Pump SN:17102938 Transfer Pump Blade Sides with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 43. Pump SN:17102938 Driveshaft Drive Tang before Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

Figure 44. Pump SN:17102938 Driveshaft Drive Tang with 500-Hours Testing with 20/80 DSH8/JP-8 Fuel with 9-ppm CI/LI

5.6 ROTARY PUMP FUEL DEPOSITION

During the component inspections and noted in Table 11 and Table 12, was evidence of brown fuel deposits on some of the components, particularly on the transfer pump regulator. Inspection of the transfer pump endplate and pressure regulator revealed a particularly heavy and sticky deposit for one of the test pumps. Figure 45 shows three fuel injection pump endplates, the plates at each end are the DSH8 pump test plates, and the plate in the middle is from a 210-hour ATJ engine test. The heavy brown deposit on the left most plate was sticky and tacky. Figure 46 shows the liner side of the transfer pump regulator plates with fuel deposition evident. Fuel deposition was heavier and stickier for the plate from pump SN:17102938.

Figure 45. Transfer Pump Endplate Deposition: DSH8 SN:17102938 Endplate Left, ATJ Engine Test Endplate Middle, and DSH8 SN:17102937 Endplate Right

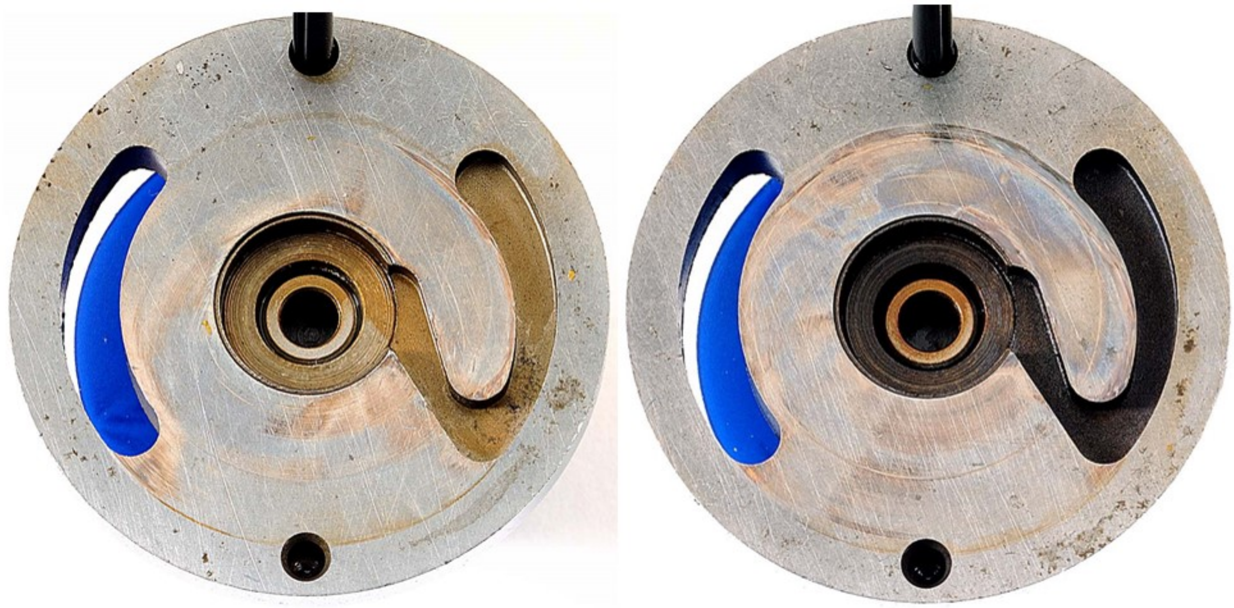


Figure 46. SN:17102937 Transfer Pump Regulator (Left) and SN:17102938 Transfer Pump Regulator (Right)

Efforts were made to determine the make-up of the sticky brown deposit seen in one of the fuel injection pumps by GC/MS. The fuel pump part was submitted for analysis of deposits that coated the surface of the part. Three solvents were used: Methanol (MeOH), Methylene Choride (DCM), and a 50/50 mix of Toluene/Acetone (Tol Act).

Individual cotton swabs were soaked with one of the solvents, and then used to try to remove some of the surface deposits. In each case, the swabs became discolored, indicating that some deposit material was removed from the part. Each swab was then allowed to soak in its respective solvent overnight. This was done to desorb any deposits from the swab. NOTE: Each swab was still discolored, indicating limited desorption. The individual solvents, with the desorbed deposit material, were then analyzed by gas chromatography/mass selective detector, as listed below in Table 13, Table 14, and Table 15.

Table 13. Gas Chromatography Conditions

Agilent 6890 GC System	
Oven:	Initial Temperature = 50 °C
	Temperature Ramp Rate = 10 °C / min
	Final Temperature = 350 °C
Inlet:	Mode = Split-less Injection
	Temperature = 350 °C
	Pressure = 7.9 psi @ 50 °C (1 ml/min flow rate)

Table 14. Analytical Column Parameters

Analytical Column: Zebron HT-5	
Length	30 meters
Inside Diameter	0.25 mm
Film Thickness	0.25 µm
Carrier Flow	1 ml/min

Table 15. Mass Spectrometer Conditions

Mass SpecTROMETER Conditions (Agilent 5973 Mass Selective Detector)	
MS Transfer Line	350 °C
MS Quad	150 °C
MS Source	230 °C
Solvent Delay	4.0 min
Scan Parameters:	Low mass = 10
	High mass = 800
Data Processing:	MSD Chemstation D.02.00.275

The chromatograms of the MeOH and Tol Act soluble deposits had similar profiles. Both had indications of phthalates present. This is likely evidence of plasticizer from a sample/storage bottle, which was leached from the bottle by the fuel or the solvent.

The MeOH soluble analysis also indicated the presence of glycerol. This is a possible indicator of contaminants remaining in the fuel from the fuel production process. Identifications for some of the other significant peaks were inconclusive.

The DCM chromatogram had a different profile compared to the other two. There was an indication of dodecanol (C12 alcohol) present. This may also be left-over from the production process. Identifications for some of the other significant peaks were inconclusive.

The above results support a recommendation of additional analysis of the fuel used for this testing. The test fuel may contain undesirable contaminants that came from the production process and it could be informative to do additional analyses to confirm.

GCMS analyses were performed on the fuel blend, a recycled sample of the fuel blend, as well as the two individual fuel blend components.

One of the fuel blend components was JP-8 with a boiling range of approximately n-C7 (98.4 °C) to n-C16 (287.2 °C). No unusual compounds were present in the JP-8 fuel.

The other fuel blend component was Farnesane, a renewable single component bio-jet fuel. Only a few minor impurities were detected in the material, including a trace amount of trimethyl dodecanol. The ASTM D7566 specification for synthetic aviation jet fuel made from hydroprocessed fermented sugars allows up to 1.5 wt.% maximum of the alkyl alcohol 3,7,11-trimethyl-1-dodecanol.[7]

The recycled fuel blend sample did not show any material that was not also in the fuel blend. GCMS results did not show any unexpected material or potential contaminants in any of the analyses.

6.0 DISCUSSION OF RESULTS

In a prior study [2] the effect of synthetic fuel on the durability of the Stanadyne arctic rotary fuel injection pump that contains hardened parts was examined. This fuel injection pump is found on the HMMWV. In conducting the pump stand test with neat synthetic fuel, it was found that the tests had to be stopped prematurely due to fuel injection performance issues that ultimately could affect the operation of an engine.

Comparison results from various synthetic fuel programs were reviewed [2,3,5]. The comparisons of synthetic fuels performance in rotary fuel injection pumps discussed, suggested that synthetic kerosene fuels, when utilized neat, resulted in premature component wear. On a positive note, reference 3 also performed tests with CI/LI additives in synthetic fuel that showed a substantial improvement of rotary fuel injection pump durability with additive treated synthetic fuel.

A study [4] was performed to determine the impacts of a QPL-25017 CI/LI additive on fuel injection pump durability with synthetic fuel. A CI/LI additive was used at the maximum permitted 24-ppm concentration in a synthetic fuel and in a 50/50-percent blend of synthetic/Jet-A fuel. In conducting the pump stand tests at 40 °C with the two fuels, it was found that both tests had completed 500-Hours of operation with minimal impact on the performance or durability of the diesel engine fuel injection systems that included the fuel injection pump and fuel injectors.

A recent study [6] was performed to determine the impact of minimal QPL-25017 CI/LI additive levels on fuel injection pump durability with a synthetic fuel. The minimal additive levels were determined by the additive concentration that resulted in an ASTM D 5001 BOCLE wear scar in the synthetic fuel of 0.75-mm (8.5-ppm CI/LI additive) and 0.83-mm (2.75-ppm CI/LI additive). Both additive concentrations evaluated were below the QPL-25017 minimum effective concentration for the CI/LI additive used. Both additive levels evaluated were considered inadequate for rotary fuel injection pump protection.

A US ARMY study looked at CI/LI additive concentrations in synthetic and petroleum aviation kerosene fuels at elevated temperatures [2,4]. The results concluded that the maximum allowable level of CI/LI was required to maintain fuel injection pump durability at elevated temperature. One

QPL-25017 CI/LI product appeared to result in improved component conditions over the other products evaluated. The study looked at only the addition of CI/LI in Jet-A or SPK fuel, and did not look at the other MIL-DTL-83133H additives that make JP-8.

Prior [8] testing with a 25/75 ATJ/JP-8 fuel with 9-ppm CI/LI, the minimum effective treat rate of the additive, indicated insufficient fuel lubricity for operation at 77 °C fuel inlet temperature. Relatively short time failures, severe component wear, and excessive drive shaft wear resulted in either a seizure or erratic pump performance. Subsequent testing of the 25/75 ATJ/JP-8 fuel with 24-ppm CI/LI permitted completion of the 1000-hours in the rotary diesel fuel injection pump testing, but one fuel injection pump's performance could not be measured due to erratic operation. One fuel injection pump would not allow idle operation if it was installed on an engine and the engine would be low on power. Component inspections suggest the transfer pump and drive tang wear was excessive and the cam ring and roller interface wear was high for both pumps. As seen in previous work [2,3,4], the maximum effective concentration of CI/LI additive is suggested for synthetic fuel blends in order to offer adequate rotary diesel fuel injection pump wear protection, but at elevated temperature even the maximum treatment levels appear inadequate for a 25/75 ATJ/JP-8 blend.

The 20/80 DSH8/JP-8 blend had an ASTM D5001 lubricity of 0.529-mm wear scar when treated with 9-ppm of the CI/LI additive DCI-4A. The ASTM D6079 wear scar diameter result for the same blend was 670-µm.

The 20/80 DSH8/JP-8 fuel with 9-ppm CI/LI permitted completion of the 500-Hours in the rotary diesel fuel injection pump test at elevated 77 °C fuel inlet temperature. Both fuel injection pumps would have compromised over-speed protection if installed on an engine, but would provide full power and torque. Component inspections suggest the transfer pump liner wear was high for both pumps. At elevated temperature in previous work (1,3,4,6), the maximum effective concentration of CI/LI additive is suggested for synthetic fuel blends in order to offer adequate rotary diesel fuel injection pump wear protection, but with the 20/80 DSH8/JP-8 fuel blend the minimum treatment level was borderline effective.

Noted with the 20/80 DSH8/JP-8 fuel blend was deposition on pump components, with some of the deposits being sticky. Analysis of the deposit and the fuel blend components suggest the deposit was possibly from a trace alkyl alcohol in the Farnesane (DSH8) blend component, although the analysis was not definitive.

7.0 CONCLUSIONS

The following conclusions can be made from the cumulative knowledge of utilizing JP-8, synthetic aviation kerosene fuel blends, and 20/80 DSH8/JP-8 in diesel rotary fuel injection pumps at elevated temperature:

- For elevated fuel inlet temperature operation, even with petroleum JP-8 at 77 °C, the maximum effective CI/LI concentration is required to provide adequate wear protection.
- For elevated fuel inlet temperature operation, with 20/80 DSH8/JP-8 at 77 °C, the minimum effective CI/LI concentration proved to be borderline effective for the 500-Hours of testing.
- A 20/80 blend of DSH8/JP-8 with 9-ppm CI/LI operated at 77 °C fuel inlet temperature will allow 500-Hours of rotary pump operation. However the performance degradation of the fuel injection pumps at 500-Hours could impact engine governor operation, and component inspections suggested excessive transfer pump liner wear.
- A possible source of pump fuel deposition was a trace alkyl alcohol constituent allowable in the DSH8 (Farnesane) fuel blend component.

8.0 RECOMMENDATIONS

The technical feasibility of using DSH8/JP-8 fuel at elevated temperatures in rotary fuel injection equipment when blended with a CI/LI additive has been investigated:

- At the minimum effective concentration of a QPL-25017 CI/LI additive, DSH8/JP-8 blends can be utilized in regions where rotary fuel injection pump equipped engines are exposed to elevated fuel inlet temperatures for short durations.
- It is recommended that blends of DSH8/JP-8 fuels include the addition of the maximum effective concentration of CI/LI for use in diesel rotary fuel injection equipment at elevated ambient temperatures to reduce transfer pump wear for longer exposure durations.

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